APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTOR(S):   Ryuzo IGA
                Yasuhiro KONDO

INVENTION:SEMICONDUCTOR OPTICAL DEVICE AND
          A METHOD OF FABRICATING THE SAME

S P E C I F I C A T I O N

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DESCRIPTION

SEMICONDUCTOR OPTICAL DEVICE AND
A METHOD OF FABRICATING THE SAME

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TECHNICAL FIELD

[0001] The present invention relates to a
semiconductor optical device and a method of
fabricating the same.

10

BACKGROUND ART

[0002] A buried structure having a semiconductor
crystal as a current-blocking burying layer is used in
a semiconductor optical device such as a semiconductor
15 laser. This structure is very important in the
practical use of a device because it has advantages
such as reduction in threshold current of a
semiconductor laser due to a good current-blocking,
stabilization of an optical beam by transverse mode
20 control, good heat dissipation from an active layer
due to a semiconductor burying layer, and high long-
term reliability.
[0003] A directly modulated laser which is one of
components necessary for a large capacity optical
25 transmission system is an important component as a
light source of a middle/short-distance high speed
optical transmission system. Thus, reduction in cost

is strongly required for the directly modulated laser. More specifically, in order to reduce the cost, it becomes necessary to operate the directly modulated laser under an uncooled condition in which no cooling

5   system such as a Peltier element is used in the mounting of the laser device, and improve fabrication yield. Consequently, the characteristics permitting the directly modulated laser to operate at a higher temperature and at a high speed are desired.

10   [0004] In order that the directly modulated laser may operate at the higher temperature and at the high speed, it is required to reduce a capacitance of the laser device and increase an light output power efficiency at a high temperature. As for the

15   principles of an operation of this directly modulated laser, a light output power of the laser is directly modulated by modulating an injection current to the laser. A modulation speed is limited by a relaxation oscillation frequency and a device capacitance of the

20   laser. The modulation speed increases as the relaxation oscillation frequency becomes higher. In order to increase the relaxation oscillation frequency, it is necessary to reduce lifetime of photons and increase a differential gain and photon density.

25   [0005] The semiconductor buried structure is roughly classified into buried structures using a high mesa and a low mesa. As for the buried structure using a

high mesa, a lower cladding layer, an active layer, an upper cladding layer, and a contact layer are formed on a substrate successively. Moreover, a high stripe-like mesa which is about 2 μm in mesa width and about

5 3 μm in mesa height is formed by using a dielectric mask, and a current-blocking layer is buried in both sides of the mesa to be grown, thereby forming the buried structure using a high mesa.

[0006] On the other hand, as for the buried structure

10 using a low mesa, a lower cladding layer, an active layer, and a part of an upper cladding layer are formed on a substrate successively, and a low stripe-like mesa which is about 2 μm in mesa width and about 1.5 μm in mesa height is formed by using a dielectric

15 mask. Moreover, after a current-blocking layer is buried in the both sides of the mesa to be grown and the dielectric mask is then removed, an upper over-cladding layer and a contact layer are grown, thereby completing the buried structure using a low mesa. In

20 order to enhance the light output power efficiency at the high temperature in the laser device such as the directly modulated semiconductor laser, the buried structure using a low mesa is suitable for attaining this rather than the buried structure using a high

25 mesa. The reason for this is that a device resistance can be reduced since an area of an upper electrode obtained in the buried structure using a low mesa can

take a larger value than that in the buried structure using a high mesa.

[0007] In addition, since the buried structure using a low mesa is low in mesa height, the burying growth for the buried structure using a low mesa is easier than that for the buried structure using a high mesa and thus the irregular crystal growth hardly occurs. As a result, it is possible to form the burying layer which is excellent in crystal quality. However, in case of the buried structure using a low mesa, in order to obtain the thickness of the burying layer required to sufficiently operate the current-blocking, the height of the surface of the burying layer becomes higher than that of the mesa. Thus, the surface after the burying growth is performed for the mesa has a concavo-convex shape. When the over-cladding layer and the contact layer are further grown on the surface having the concavo-convex shape, the concavo-convex shape remains on the contact layer as well. Though the over-cladding layer is ordinarily a binary semiconductor compound crystal, since the contact layer is ordinarily made of a semiconductor compound alloy crystal such a ternary or more complex alloy crystal, the composition change of the contact layer occurs. As a result, the lattice mismatch is generated between the over-cladding layer and the contact layer. Thus, there is encountered such a

problem that the degradation of the crystal quality
due to the strain is caused.

[0008] This problem causes the degradation of the in-
plane fabrication yield and run-to-run reproducibility
5 as well as the degradation of the device
characteristics. Thus, the concavo-convex shape
before the growth of the contact layer, i.e., after
the growth of the over-cladding layer needs to be
flattened so as not to cause a problem in the crystal
10 quality of the contact layer.

[0009] In addition, the conductivity type of the
substrate served to the fabrication of the
semiconductor optical device exerts a large influence
on the device characteristics. A lower substrate
15 electrode able to obtain a large contact area is made
of a p-type semiconductor whose contact resistance is
larger than that of an n-type semiconductor, whereby
the device resistance can be reduced and thus the
device characteristics can be enhanced. When the
20 substrate is a p-type substrate, the directly
modulated semiconductor laser for which the high speed
operation is required has an advantage of obtaining
compatibility with an npn-type transistor circuit
which is excellent in high speed operation.
25 Consequently, in the semiconductor laser device,
especially, in the directly modulated laser, the
buried structure using a low mesa on the p-type

substrate is effective. Moreover, a device structure which has excellent device characteristics and with which the fabrication yield and the run-to-run reproducibility are enhanced, and a fabrication method

5   thereof are essential to reduction in cost of the device.

[0010] [Patent document 1] U.S.Patent No.5470785

[Non-patent document 1] A. Dadgar et al, "Ruthenium: A superior compensator of InP", Applied Physics Letters

10   Vol.73, No.26, pp.3878-3880, 1998

[Non-patent document 2] A. van Geelen et al, "Ruthenium doped higher power 1.48 µm SIPBH laser", 11th International conference on Indium Phosphide and related materials Tubl-2, 1999

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DISCLOSURE OF THE INVENTION

[0011] There is encountered such a problem that the concavo-convex shape before the growth of the contact layer, i.e., after the growth of the over-cladding

20   layer must be flattened so as not to cause a problem in the crystal quality of the contact layer in order to provide the excellent device characteristics and enhance the fabrication yield and the run-to-run reproducibility in the buried structure using a low

25   mesa on the p-type substrate.

[0012] In order to solve the above-mentioned problem, in a semiconductor optical device in which a mesa-

stripe stacked body including at least a p-type
cladding layer, an active layer, and an n-type
cladding layer is formed on a p-type semiconductor
substrate, a current-blocking layer is buried in both
5   sides of the stacked body, and an n-type over-cladding
layer and an n-type contact layer are regrown on the
current-blocking layer and the stacked body. The n-
type over-cladding layer is made of a semiconductor
crystal having a property for flattening the concavo-
10 convex shape of upper surfaces of the current-blocking
layer and the stacked body.
[0013] Preferably, an n-type dopant for the
semiconductor crystal is a group VI element, and
moreover selenium is suitable for the n-type dopant
15 for the semiconductor crystal. In addition, doping
concentration of selenium is suitably equal to or
higher than 5×10^{18} cm^{-3}.

BRIEF DESCRIPTION OF THE DRAWINGS
20 [0014] [FIG. 1A] FIG. 1A is a cross sectional view
showing a process for fabricating a semiconductor
device according to Embodiment 1 of the present
invention;
[FIG. 1B] FIG. 1B is a cross sectional view showing a
25 process for fabricating a semiconductor device
according to Embodiment 1 of the present invention;
[FIG. 1C] FIG. 1C is a cross sectional view showing a

process for fabricating a semiconductor device

according to Embodiment 1 of the present invention;

[FIG. 1D] FIG. 1D is a cross sectional view showing a

process for fabricating a semiconductor device

5   according to Embodiment 1 of the present invention;

[FIG. 1E] FIG. 1E is a cross sectional view showing a

process for fabricating a semiconductor device

according to Embodiment 1 of the present invention;

[FIG. 1F] FIG. 1F is a cross sectional view showing a

10   process for fabricating a semiconductor device

according to Embodiment 1 of the present invention;

[FIG. 1G] FIG. 1G is a cross sectional view showing a

process for fabricating a semiconductor device

according to Embodiment 1 of the present invention;

15   [FIG. 2A] FIG. 2A is a cross sectional view showing a

structure of a device whose degree of flattening is

measured;

[FIG. 2B] FIG. 2B is a diagram showing a relationship

between doping concentration of Se and the degree of

20   flattening;

[FIG. 3] FIG. 3 is a diagram showing dependence of

optical small-signal response characteristics of a

directly modulated semiconductor laser on a

temperature;

25   [FIG. 4A] FIG. 4A is a cross sectional view showing a

process for fabricating a semiconductor device

according to Embodiment 2 of the present invention;

[FIG. 4B] FIG. 4B is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 2 of the present invention;

[FIG. 4C] FIG. 4C is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 2 of the present invention;

[FIG. 4D] FIG. 4D is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 2 of the present invention;

[FIG. 4E] FIG. 4E is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 2 of the present invention;

[FIG. 4F] FIG. 4F is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 2 of the present invention;

[FIG. 4G] FIG. 4G is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 2 of the present invention;

[FIG. 5A] FIG. 5A is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 3 of the present invention;

[FIG. 5B] FIG. 5B is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 3 of the present invention;

[FIG. 5C] FIG. 5C is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 3 of the present invention;

[FIG. 5D] FIG. 5D is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 3 of the present invention;

[FIG. 5E] FIG. 5E is a cross sectional view showing a
5 process for fabricating a semiconductor device according to Embodiment 3 of the present invention;

[FIG. 5F] FIG. 5F is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 3 of the present invention;
10 and

[FIG. 5G] FIG. 5G is a cross sectional view showing a process for fabricating a semiconductor device according to Embodiment 3 of the present invention.

15 BEST MODE FOR CARRYING OUT THE INVENTION
[0015] Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings. Normally, a cross sectional configuration of a device after burying growth is
20 performed for a low mesa structure formed on a p-type substrate becomes a cross sectional configuration having the concavo-convex shape. Thus, with the conventional method, after an over-cladding layer and a contact layer are formed, the concavo-convex shape
25 remains. As a result, it becomes difficult to control the crystal quality of the contact layer using an alloy crystal such as a ternary or more complex alloy

crystal, which remarkably degrades the characteristics of the device. Thus, in embodiments, after the burying growth is performed for a low mesa structure, an over-cladding layer is used which is made of a

5   crystal having a property for flattening a cross sectional configuration having irregularity.

[0016] The embodiments are devices having a buried structure using a low mesa which is formed on a p-type substrate. After a current-blocking layer is buried

10   in both sides of a mesa, the over-cladding layer is used which is made of the crystal having the property for flattening the concavo-convex shape of a surface after the burying growth is performed for the mesa, thereby obtaining the crystal quality of the contact

15   layer not degrading the device characteristics. Since the over-cladding layer made of the crystal having the property for flattening the concavo-convex shape of the surface is used in the manner described above, even when the surface having the concavo-convex shape

20   is formed after the current-blocking layer is buried in the both sides of the mesa, the surface of the over-cladding layer becomes flat. For this reason, even when the contact layer is formed on the over-cladding layer, it is possible to obtain the contact

25   layer not degrading the device characteristics.

[0017] An example of the over-cladding layer for flattening the concavo-convex shape of the surface

after the burying growth is performed for the mesa is
a semiconductor crystal doped with selenium (Se). The
over-cladding layer has a large flattening effect as
the concentration of Se for doping is higher. It is

5   desirable that the doping concentration of Se is equal
to or higher than 5×10^{18} cm^{-3}. More specifically, in
a device having a buried structure using a low mesa
which is formed on a p-type InP substrate, an InP
crystal having Se doping concentration of 5×10^{18} cm^{-3}

10   or more is used as the n-type over-cladding layer,
whereby the results are obtained which are more
effective in flattening. The details will be
described later with reference to Embodiment 1.
[0018] As regards the buried structure which can be

15   applied to the device having the buried structure
using a low mesa, there are a structure formed of only
a high-resistive burying layer using a semi-insulating
semiconductor crystal, a pn-type semiconductor buried
structure, and a buried structure using both a semi-

20   insulating semiconductor crystal and an n-type
semiconductor crystal. The excellent effects in the
embodiments can be obtained in any of those buried
structures. In the three kinds of buried structures
described above, it is desirable that a current-

25   blocking buried structure of the device is a simple
structure in order to further enhance the device
characteristics, in-plane fabrication yield, and run-

to-run reproducibility of the buried structure using a low mesa.

[0019] A complicated multilayer buried structure becomes a main factor that causes the degradation of the device characteristics due to an increase in leakage current, the reduction in yield within a substrate plane, and the reduction in run-to-run reproducibility. In order to make the current-blocking buried structure a simple structure, preferably a structure using only a semi-insulating semiconductor crystal is used. Heretofore, a semiconductor crystal doped with iron (Fe) has been used as the high-resistive burying layer using the semi-insulating semiconductor crystal. However, there is encountered such a problem that Fe as the dopant and zinc (Zn) as a dopant for the p-type semiconductor crystal causes inter-diffusion in a burying growth interface.

[0020] As a result, since Zn deeply diffuses into a burying layer doped with Fe to degrade the semi-insulating property of the burying layer, thereby degrading the current-blocking property, this becomes a main factor that causes the degradation of the device characteristics. In recent years, it has been found out that the semi-insulating semiconductor crystal doped with Ru hardly causes the inter-diffusion with Zn, and thus the semiconductor laser

using the semi-insulating burying layer containing Ru
as a dopant on the n-type InP substrate has been
fabricated (refer to Non-patent documents 1 and 2 for
example). Thus, when a high-resistive layer made of a

5   semi-insulating crystal containing Ru as a dopant is
buried, a simple buried structure is realized. As a
result, the excellent effects are obtained because of
enhancement of the device characteristics, the
fabrication yield, and the reproducibility.

10 [0021] According to the embodiments, it is possible to
realize the excellent device characteristics, the
enhancement of the fabrication yield within a
substrate plane, and the satisfactory run-to-run
reproducibility. In addition, when the high-resistive

15 layer made of the semi-insulating crystal containing
Ru as a dopant is buried, a simple buried structure is
realized. As a result, the satisfactory effects are
obtained because of enhancement of the device
characteristics, the fabrication yield, and the

20 reproducibility. In particular, when the present
invention is applied to the directly modulated
semiconductor laser, the cost can be reduced.

Embodiment 1

25 [0022] FIGS. 1A to 1G show processes for fabricating a
semiconductor device according to a first embodiment
of the present invention. These figures are cross

sectional views of a directly modulated semiconductor DFB laser using an MQW as an active layer. Firstly, as shown in FIG. 1A, a Zn-doped p-type InP cladding layer 2 having a layer thickness of 0.5 μm, a

5 nondoped-InGaAsP lower separate confinement heterostructure (SCH) layer 3 having a layer thickness of 0.05 μm, a non-doped InGaAsP/InGaAsP strain multiple quantum well (MQW) active layer 4 having a layer thickness of 0.15 μm and having a bandgap

10 wavelength of 1.3 μm, and a non-doped InGaAsP upper separate confinement heterostructure (SCH) layer 5 having a layer thickness of 0.05 μm were grown in order on a Zn-doped p-type InP substrate 1 having surface orientation (100) by utilizing a metal organic

15 vapor-phase epitaxy (MOVPE) method. After a diffraction grating was formed on an upper portion of the InGaAsP upper separate confinement heterostructure (SCH) layer 5, a Se-doped n-type InP cladding layer 6 having a layer thickness of 0.2 μm was grown.

20 [0023] Next, as shown in FIG. 1B, a mesa stripe which was 2 μm in width and about 1.5 μm in height was formed with SiO_2 as a mask 7 by utilizing reactive ion etching (RIE). Subsequently, as shown in FIG. 1C, a Ru-doped InP layer 8 (having a layer thickness of 3

25 μm) was grown as a current-blocking layer on the substrate on both sides of the mesa stripe by utilizing the MOVPE method.

Bis(ethylcyclopentadienyl) ruthenium (II) was used as a source material for Ru. A layer thickness of the Ru-doped InP layer 8 was 3 μm in a flat region (reference symbols a, a' in FIG. 1C) which was at a distance from a rising buried region in the vicinity of the mesa.

[0024] As shown in FIG. 1D, when the mask 7 made of SiO_2 was removed, a V-shaped-like groove having a depth of 1.5 μm or more was formed. In order to flatten this groove, as shown in FIG. 1E, an n-type InP over-cladding layer 9 doped with Se was grown by utilizing the MOVPE.

[0025] A description will be given with respect to concentration of Se with which the over-cladding layer is doped. Kondo as one of the inventors of this application makes it clear that as the doping concentration of Se increases, the degree of flattening increases (refer to Patent document 1 for example). An influence of the doping concentration of Se exerted on the degree of flattening will be described based on this fact. The degree of flattening when as shown in FIG. 2A, a Zn-doped p-type InP (102) having a layer thickness of 1.0 μm was grown over a mesa 101 which was 2.1 μm in width and 1.0 μm in height, and a Se-doped n-type InP (103) having a layer thickness of 0.8 μm was further grown was measured. A layer thickness of the Se-doped n-type

InP (103) over the mesa is assigned d, a layer thickness of a flat region at a distance from the mesa is assigned d_0, and the degree of flattening is assigned d/d_0. That is, this means that the degree of

5 flattening is higher as d/d_0 becomes smaller.

[0026] FIG. 2B shows a relationship between the doping concentration of Se and the degree of flattening. It is understood that as the doping concentration of Se increases, d/d_0 decreases and thus the degree of

10 flattening becomes high. Then, the doping concentration of Se at which d/d_0 became equal to or smaller than 1/2 was equal to or higher than 5×10^{18} cm^{-3}.

[0027] In this embodiment, if the layer thickness of

15 the n-type InP over-cladding layer doped with Se fulfills a relationship of $d/d_0 < 1/2$, the concavo-convex shape of the groove can be flattened while an increase in layer thickness in the flat region is suppressed as much as possible, and thus this process

20 can be applied to the fabrication of the device.

[0028] Incidentally, while the doping of Se has been described here, it is known that with respect to sulfur (S) and tellurium (Te) as well which belong to the same group VI element as that of Se, as the doping

25 concentration increases, the degree of flattening increases.

[0029] As shown in FIG. 1E, an n-type InP over-

cladding layer 9 having a layer thickness of 2 μm and having Se doping concentration of 6×10^{18} cm^{-3} was grown by utilizing the MOVPE, thereby flattening the concavo-convex shape after growth of the current-blocking layer. Here, the layer thickness of the n-type InP over-cladding layer 9 means a thickness in a flat region (reference symbols a, a' in FIG. 1E) of the Ru-doped InP layer 8 at a distance from a rising buried region thereof in the vicinity of the mesa.

[0030] Thereafter, as shown in FIG. 1F, an n-type indium gallium arsenide phosphorus (InGaAsP) contact layer 10 having a layer thickness of 0.4 μm and containing Se as a dopant was grown by utilizing the MOVPE. Each compound semiconductor other than that of the active layer has composition lattice-matching with the InP substrate unless especially notice is given.

[0031] Next, as shown in FIG. 1G, an n-type electrode 11 was formed and a p-type electrode 12 was formed on a substrate side. Thereafter, while not illustrated, in order to reduce a capacitance of the whole device as much as possible, the unnecessary Ru-doped InP layer 8, n-type InP over-cladding layer 9 and contact layer 10 which were at a distance from the mesa stripe shown in FIG. 1B were etched away by utilizing dry etching, thereby obtaining such a mesa structure as to include the mesa stripe. At this time, reducing the layer thickness of the whole device as much as

possible is advantageous in that the mesa structure is
easy to optimize, the device capacitance can be
reduced, and no device characteristics are degraded.
On the other hand, in order to reduce the device

5   capacitance and reduce a forward leakage current, it
is advisable to increase the layer thickness of the
Ru-doped InP layer 8 as the semi-insulating layer as
much as possible. Consequently, when the layer
thickness of the n-type InP over-cladding layer 9 is

10 reduced as much as possible, this is advantageous in
enhancement of the device characteristics since an
increase in layer thickness of the whole device can be
suppressed. When the concavo-convex shape of the
groove is flattened, if the doping concentration of Se

15 is increased, so that the flattening can be made with
the thinner n-type InP over-cladding layer 9, the
effects of the present invention become more
remarkable.

[0032] FIG. 3 shows dependence of optical small-signal

20 response characteristics of a directly modulated
semiconductor laser fabricated by using the method
described above on a temperature. A 3-dB bandwidth of
the semiconductor laser is about 25 GHz at a chip
temperature of 25°C, about 18 GHz at 85°C, and about

25 15 GHz at 95°C. A threshold current is about 6 mA at
the chip temperature of 25°C, and about 32 mA at 95°C.
Light output power efficiency is about 0.38 W/A at the

chip temperature of 25°C, and about 0.16 W/A at 95°C.

[0033] On the other hand, when the Se doping
concentration of the n-type InP over-cladding layer 9
is lower than 5 × 10^{18} cm^{-3}, the flattening of the

5   concavo-convex shape of the surface is insufficient.
As a result, the crystal quality of the n-type InGaAsP
contact layer 10 is degraded to cause the degradation
of the device characteristics.

[0034] Next, a description will be given with respect

10   to a case where the layer thickness of the Ru-doped
InP layer 8 is further increased. A directly
modulated semiconductor laser was fabricated under the
conditions in which the Se doping concentration for
the n-type InP over-cladding layer 9 was set to 8 ×

15   10^{18} cm^{-3}, and the layer thickness of the n-type InP
over-cladding layer 9 was set to 1 µm. At this time,
the layer thickness of the Ru-doped InP layer 8 was 4
µm. A 3-dB bandwidth of the optical small-signal
response characteristics of the directly modulated

20   semiconductor laser was about 28 GHz at the chip
temperature of 25°C, and about 17 GHz at 95°C. The
threshold current was about 5 mA at the chip
temperature of 25°C, and about 27 mA at 95°C. The
light output power efficiency was about 0.40 W/A at

25   the chip temperature of 25°C, and about 0.18 W/A at
95°C. Comparing the device characteristics of this
directly modulated laser with those of the directly

modulated laser shown in FIG. 3, it is understood that the device characteristics are enhanced.

[0035] Moreover, a directly modulated semiconductor laser was fabricated under the condition in which the Se doping concentration for the n-type InP over-cladding layer 9 was set to 8×10^{19} cm^{-3}. At this time, the layer thickness of the Ru-doped InP layer 8 was 5 μm. The n-type InP over-cladding layer 9 was hardly grown in the flat region of the Ru-doped InP layer 8 at a distance from the rising buried region thereof in the vicinity of the mesa, and thus was grown while maintaining the V-shaped-like groove structure, thereby flattening the concavo-convex shape. The 3-dB bandwidth of the optical small-signal response characteristics of the directly modulated semiconductor laser was about 30 GHz at the chip temperature of 25°C, and about 19 GHz at 95°C. The threshold current was about 5 mA at the chip temperature of 25°C, and about 24 mA at 95°C. The light output power efficiency was about 0.42 W/A at the chip temperature of 25°C, and about 0.20 W/A at 95°C. Comparing the device characteristics of this directly modulated laser with those of the directly modulated lasers described above, it is understood that the device characteristics are further enhanced.

[0036] In such a manner, an increase in layer thickness of the Ru-doped InP layer 8 as the current-

blocking layer reduces the forward leakage current of the directly modulated semiconductor laser. Hence, the light output power efficiency increases and the device capacitance decreases, so that the modulation

5 characteristics are remarkably enhanced.

[0037] Heretofore, it has been tried to increase the layer thickness of the semi-insulating layer as the current-blocking layer to enhance the device characteristics. However, an increase in layer

10 thickness of the semi-insulating layer made the concavo-convex shape of the groove deep. As a result, it became difficult to bury the over-cladding layer in the groove to flatten the concavo-convex shape, and also the total layer thickness of the device increased.

15 On the other hand, if the layer thickness of the over-cladding layer is further reduced, this caused such a problem that it was more difficult to flatten the concavo-convex shape. According to this embodiment mode, the n-type InP over-cladding layer having the Se

20 doping concentration of 5×10^{18} cm^{-3} or more is used, whereby it is possible to form the thinner over-cladding layer and the thicker semi-insulating layer. Hence, it is possible to enhance the device characteristics of the directly modulated

25 semiconductor laser.

Embodiment 2

[0038] FIGS. 4A to 4G show processes for fabricating a
semiconductor device according to a second embodiment
of the present invention. These figures are cross
sectional views showing a directly modulated

5   semiconductor DFB laser having an MQW as an active
layer. Firstly, as shown in FIG. 4A, a Zn-doped n-
type InP cladding layer 22 having a layer thickness of
0.5 μm, a nondoped-InGaAsP lower separate confinement
heterostructure (SCH) layer 23 having a layer

10   thickness of 0.05 μm, a nondoped-InGaAsP/InGaAsP
strain multiple quantum well (MQW) active layer 24
having a layer thickness of 0.15 μm and having a
bandgap wavelength of 1.3 μm, and a nondoped-InGaAsP
upper separate confinement heterostructure (SCH) layer

15   25 having a layer thickness of 0.05 μm were grown in
order on a Zn-doped p-type InP substrate 21 having
surface orientation (100) by utilizing the metal
organic vapor-phase epitaxy (MOVPE) method. After a
diffraction grating was formed on an upper portion of

20   the InGaAsP upper separate confinement heterostructure
(SCH) layer 25, a Se-doped n-type InP cladding layer
26 having a layer thickness of 0.2 μm was grown.
[0039] Next, as shown in FIG. 4B, a mesa stripe which
was 2 μm in width and about 1.5 μm in height was

25   formed with SiO$_2$ as a mask by utilizing the reactive
ion etching (RIE). Subsequently, as shown in FIG. 4C,
an n-type InP layer 28 (having a layer thickness of

0.5 µm) was grown as a current-blocking layer and an Fe-doped InP layer 29 (having a layer thickness of 3 µm) was grown by utilizing the MOVPE method. Ferrocene was used as a source material for Fe.

5 [0040] As shown in FIG. 4D, when the mask 27 made of SiO_2 was removed, a V-shaped-like groove was formed. In order to flatten the concavo-convex shape of this groove, as shown in FIG. 4E, an n-type InP over-cladding layer 30 having a layer thickness of 2 µm and

10 having Se doping concentration of 6×10^{18} cm^{-3} was grown by utilizing the MOVPE.

[0041] Thereafter, as shown in FIG. 4F, an n-type indium gallium arsenide phosphorus (InGaAsP) contact layer 31 having a layer thickness of 0.4 µm and

15 containing Se as a dopant was grown by utilizing the MOVPE. Each compound semiconductor other than that of the active layer has composition lattice-matching with the InP substrate unless especially notice is given.

[0042] Next, as shown in FIG. 4G, an n-type electrode

20 32 was formed and a p-type electrode 33 was formed on the substrate side. Thereafter, the same mesa processing as that in Embodiment 1 was performed.

[0043] The optical small-signal response characteristics of a directly modulated semiconductor

25 laser fabricated by using the method described above were measured. The 3-dB bandwidth of the semiconductor laser is about 22 GHz at the chip

temperature of 25°C, and about 11 GHz at 95°C. The
threshold current is about 7 mA at the chip
temperature of 25°C, and about 35 mA at 95°C. The
light output power efficiency is about 0.35 W/A at the
5 chip temperature of 25°C, and about 0.15 W/A at 95°C.

Embodiment 3

[0044] FIGS. 5A to 5G show processes for fabricating a
semiconductor device according to a third embodiment
10 of the present invention. These figures are cross
sectional views of a directly modulated semiconductor
DFB laser having an MQW as an active layer. Firstly,
as shown in FIG. 5A, a Zn-doped p-type InP cladding
layer 42 having a layer thickness of 0.5 μm, a
15 nondoped-InGaAsP lower separate confinement
heterostructure (SCH) layer 43 having a layer
thickness of 0.05 μm, a nondoped-InGaAsP/InGaAsP
strain multiple quantum well (MQW) active layer 44
having a layer thickness of 0.15 μm and having a
20 bandgap wavelength of 1.3 μm, and a nondoped-InGaAsP
upper separate confinement heterostructure (SCH) layer
45 having a layer thickness of 0.05 μm were
successively grown on a Zn-doped p-type InP substrate
41 having surface orientation (100) by utilizing the
25 metal organic vapor-phase epitaxy (MOVPE) method.
After a diffraction grating was formed on an upper
portion of the InGaAsP upper separate confinement

heterostructure (SCH) layer 45, a Se-doped n-type InP cladding layer 46 was grown.

[0045] Next, as shown in FIG. 5B, a mesa stripe which was 2 μm in width and 1.5 μm in height was formed with SiO$_2$ as a mask 47 by utilizing the reactive ion etching (RIE). Subsequently, as shown in FIG. 5C, a p-type InP layer 48 (having a layer thickness of 0.6 μm), an n-type InP layer 49 (having a layer thickness of 0.6 μm), and a p-type InP layer 50 (having a layer thickness of 0.6 μm) were successively grown as a current-blocking layer on the both sides of the mesa stripe by utilizing the MOVPE method.

[0046] As shown in FIG. 5D, when the mask 47 made of SiO$_2$ was removed, a V-shaped-like groove was formed. In order to flatten the concavo-convex shape of this groove, as shown in FIG. 5E, an n-type InP over-cladding layer 51 having a layer thickness of 2 μm and having Se doping concentration of 6×10^{18} cm^{-3} was grown by utilizing the MOVPE.

[0047] Thereafter, as shown in FIG. 5F, an n-type indium gallium arsenide phosphorus (InGaAsP) contact layer 52 having a layer thickness of 0.4 μm and containing Se as dopant was grown by utilizing the MOVPE. Each compound semiconductor other than that of the active layer has composition lattice-matching with the InP substrate unless especially notice is given.

[0048] Next, as shown in FIG. 5G, an n-type electrode

53 was formed and a p-type electrode 54 was formed on the substrate side. Thereafter, the same mesa processing as that in Embodiment 1 was performed.

[0049] The optical small-signal response characteristics of a directly modulated semiconductor laser fabricated by using the method described above were measured. The 3-dB bandwidth of the semiconductor laser is about 15 GHz at the chip temperature of 25°C, and about 8 GHz at 95°C. The threshold current is about 8 mA at the chip temperature of 25°C, and about 35 mA at 95°C. The light output power efficiency is about 0.35 W/A at the chip temperature of 25°C, and about 0.15 W/A at 95°C.

[0050] This embodiment mode deals with the InGaAsP multiple quantum well (MQW) layer as the active layer of the laser. However, the present invention is effective in structures such as a bulk layer and a multiple quantum well layer in all systems, each having a substrate made of InP, such as an InP-InGaAsP-InGaAs system and an InAlAs-InGaAlAs-InGaAs system. In addition, even when the current-blocking buried structure adopts a layer structure other than those in the above-mentioned embodiments, the same effects are obtained. The semiconductor laser has been described in the above-mentioned embodiments. However, it is to be understood that the present invention is effective in not only other semiconductor

devices and single devices such as an optical
modulator, a semiconductor amplifier and a photodiode,
but also integrated devices such as a device having an
optical modulator integrated with a semiconductor

5   laser, and a device having a semiconductor amplifier
and an optical modulator integrated with each other.
[0051] As set forth hereinabove, this embodiment mode
relates to the semiconductor optical device such as a
semiconductor laser. Thus, even when the surface

10 becomes the concavo-convex shape after the burying
growth is performed, the over-cladding layer made of
the crystal having the property for flattening the
surface is used, thereby obtaining the contact layer
not degrading the device characteristics.

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INDUSTRIAL APPLICABILITY
[0052] The present invention is not limited to the
semiconductor laser, and thus is effective in not only
other semiconductor devices and single devices such as

20 an optical modulator, a semiconductor amplifier and a
photodiode, but also integrated devices such as a
device having an optical modulator integrated with a
semiconductor laser, and a device having a
semiconductor amplifier and an optical modulator

25 integrated with each other.